Nestlé Waters Pakistan

Islamabad Water Factory

Constructive critical review of hydrogeological reports

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1. Introduction

1.1. Context of the Study

Nestlé Waters is producing bottled water “Pure Life” in their water factory of Islamabad in Pakistan.

Groundwater resources studies have been conducted in 2013 and 2014 by two external consultants. Both studies ended up with divergent conclusions and recommendations. In this context, Nestlé Waters want to carry on the groundwater resource assessment and asked Antea Group to provide a critical review of the two previous studies in order to have a more comprehensive study including water balance, aquifer sustainability and water stewardship recommendations.

The present report treats the desktop study for which available information on geological and hydrogeological contexts was compiled and analyzed.

This draft report concludes on detailed recommendations in terms of water stewardship and aquifer sustainability.

1.2. Reference documents

The studies and documents reviewed for the hydrogeological resource assessment are listed below:

[1] Estimation of water sustainability within 30 km radius in Islamabad/Rawalpindi using hydrological&geophysical historic data (HESC, 2014)

[2] Hydrogeological study for a deep well in Islamabad (NESPAK, 2013)

[3] Environmental Geology of the Islamabad-Rawalpindi Area, Northern Pakistan (Sheikh and al., 2007, U.S. Geological Survey)

[4] Geological Map of the Islamabad-Rawalpindi Area, Punjab, Northern Pakistan (Williams and al., U.S. Geological Survey)

[5] Geology of Pakistan (Bender, Raza, 1995, Beiträge zur regionalen Geologie der Erde, Gebrüder Borntraeger)

2. Description of the Study Area

2.1. Location of the Nestlé Islamabad Water Factory

The Nestlé Water Factory is located in the Islamabad watershed (cf. Figure 1) and more specifically in Sector I-10/3 of Islamabad.

A bore well is installed in this industrial area, having a capacity of 25 m^3/h.

The map in figure 2 shows the Islamabad Water Factory in relation to Rawalpindi in the south, the Margalla Hills in the north and the Murree-Kotli Hills in the north-west.

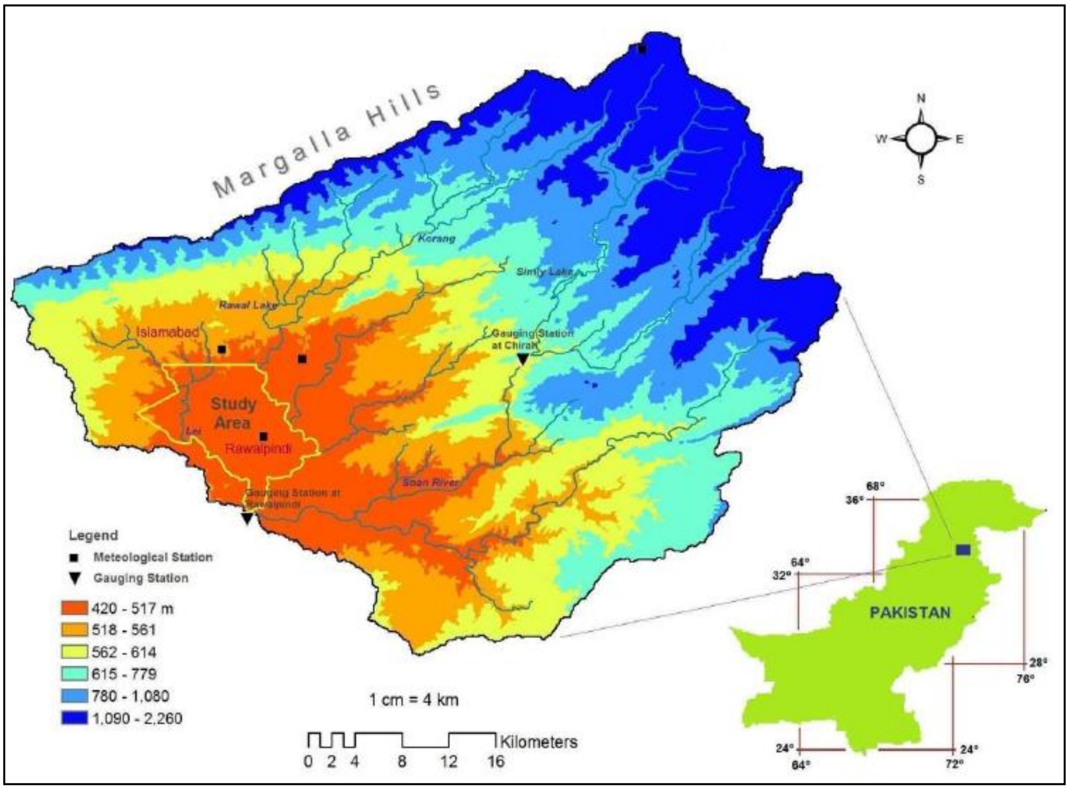

Figure 1 - Location of the Islamabad watershed (source: HESC, 2014)

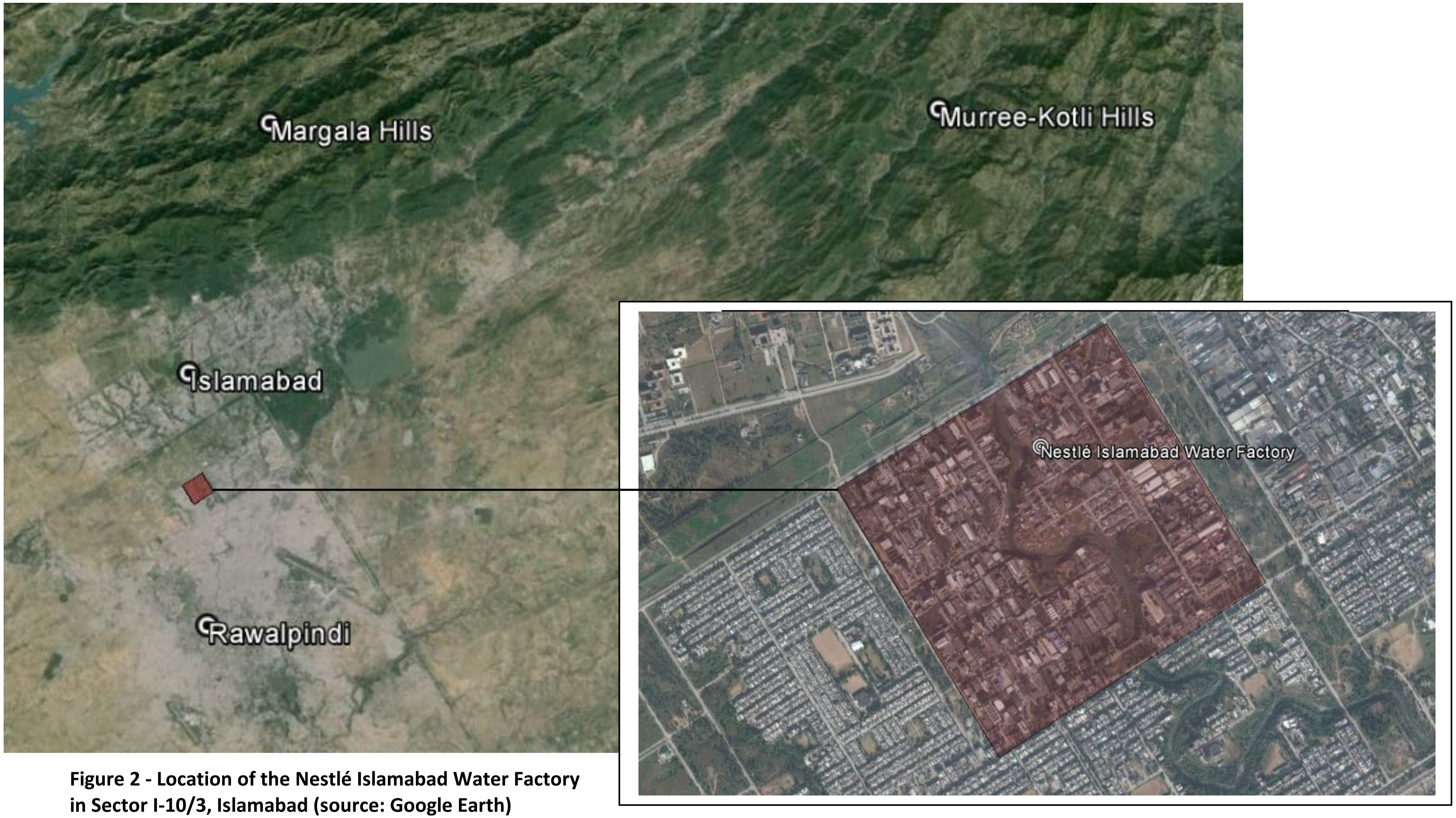

Figure 2 - Location of the Nestlé Islamabad Water Factory in Sector I-10/3, Islamabad (source: Google Earth)

2.2. Land use

The Nestlé Waters factory is located within an urbanized area.

2.3. Landforms

The study zone covers an area of several hundreds of km^2 and is located within the Potwar Plateau and particularly the Lei Nullah Basin. It is composed of plains and mountains which do not exceed an elevation of 1240 m. The terrain generally slopes from the northeast to the southwest (cf. figure 1).

Four physiographic zones can be pointed out from east-northeast to west-southwest:

- the Margalla Hills,
- the Higher Plain,
- the Lower plain,
- the Valley area.

The ground elevation of the Lei Nullah Basin is from 420 m at the downstream end of the basin (confluence of Lei Nullah and Soan River) up to 1240 m at the upstream end (a mountain top in the Margalla Hills).

Rawalpindi city area is covered with alluvium and eolian deposits and is part of dissected basin plain formed by Lei Nullah and its tributaries.

2.4. Soils

Soil in the area can derived from rocks in the province, as well as originates from fluvial deposits. In zones where depositional landforms are present, the surface can be:

- without any soil development (stream beds, low islands and bars),
- covered with fine sand, silt and clay with a relatively high organic content and fertile soil (stream flood plains),
- covered with a thin layer of fine-textured soil overlying channel deposits of sand and gravel (stream and fan terraces),
- covered with fertile and easy tilled soil overlying fine silt and clay deposits (loess plains).

In areas where erosional landforms are present, the surface can be covered with thin sandy soil derived from weathering of the underlying rock (conglomerates of the Soan formation or Lei conglomerate, Kamlial formation).

This chapter needs further current information about agriculture practices to deliver workable outcomes for an Integrated Resource Water Management study.

2.5. Climate

The Islamabad-Rawalpindi area is located in a monsoonal climate zone with rainy hot summers and cool dry winters. The monsoon period usually starts in June, peak in August and end by September. There is also a winter monsoon, much smaller than the one in summer, peaking in March.

The following subchapters present data of rainfall, evaporation and temperature.

2.5.1. *Rainfall*

Rainfall data is available from 1959 to 2012 (Islamabad Airport Station). It reveals an annual average rainfall of 1172 mm. Most of this precipitation occurs between June and October. In this period, 69 % of annual rainfall (812 mm) is measured. Between November and May, precipitation is about 360 mm.

A record of a rainfall breaking 620 mm in just 10 hours occurs on July 2001.

The monthly rainfall data between 2006 and 2012 reveal an annual mean rainfall in the watershed of 1246 mm.

2.5.2. *Evaporation*

Secondary information about evaporation in the study area originate from HESC report of 2014. According to their report, evaporation in the area is about 56 % of mean annual rainfall which comes to be 654 mm. From our experience in similar contexts, we consider this value as low.

Further data have been obtained from Meteorological Department by Nestlé Waters. A mean daily data of evapotranspiration had been provided on a monthly basis from 2006 to 2015. Daily evapotranspiration varies between 0.9 mm and 6.8 mm corresponding to a mean annual evapotranspiration of 1283 mm (see table below).

	METEORLOGICAL DATA OF EVAPOTRANSPIRATION (mm/day),RAWALPINDI											
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2006	1.3	2.0	3.4	5.7	6.6	5.2	2.7	2.6	4.3	4.8	3.4	2.1
2007	2.0	1.3	2.8	5.5	6.8	5.8	3.5	2.3	3.2	4.6	3.7	2.9
2008	2.2	1.6	2.4	5.1	6.2	5.3	4.1	2.6	3.7	3.9	3.9	3.1
2009	2.7	2.3	0.9	3.3	6.0	6.4	5.9	3.8	2.5	3.2	3.5	3.1
2010	3.2	2.3	2.4	3.2	6.7	6.1	5.5	3.4	2.3	2.0	3.4	3.2
2011	2.9	2.3	2.4	1.8	3.9	5.9	4.9	4.1	2.7	1.7	2.2	2.9
2012	2.7	2.7	2.7	1.9	2.7	4.6	5.7	4.7	3.2	1.6	1.7	2.3
2013	2.8	2.7	3.5	3.1	2.2	3.9	4.6	4.0	3.9	2.6	1.4	1.9
2014	2.4	3.0	3.3	3.2	2.5	2.1	4.0	5.4	4.2	2.9	1.2	1.3
2015	1.9	3.2	3.7	4.6	4.1	3.4	3.1	4.8	5.4	4.0	1.8	1.1

Note: This is real time data and not meant for litigation.

Table 1 - Meteorological data of Evapotranspiration (mm/day)

2.5.3. *Air temperature*

The mean minimal and maximal temperatures for each month between 2006 and 2015 show that the monthly amplitude is very important (between 5.3 and 20.4 °C). The average amplitude is about 14.4 °C. The highest temperature measured between 2006 and 2015 is 42°C in May 2011, the lowest temperature was measured in December 2011 (0.5°C) (see tables below).

	METEORLOGICAL DATA OF MEAN MAXIMUM TEMPERATTURE (°C),RAWALPINDI											
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2006	18.3	25.0	26.2	32.7	39.1	37.7	34.6	32.9	33.7	31.3	24.1	18.3
2007	19.7	19.3	23.1	33.9	37.3	37.6	35.2	34.2	32.8	31.5	26.1	20.1
2008	15.2	19.3	29.8	29.7	36.9	34.7	35.1	33.3	33.1	31.0	25.2	20.1
2009	18.9	20.4	25.0	29.4	36.6	38.9	38.2	35.0	34.0	32.1	24.3	20.7
2010	20.9	19.5	29.4	34.2	36.8	38.4	36.4	32.5	31.9	30.8	26.2	20.3
2011	16.8	17.9	26.5	29.6	42.0	38.8	34.0	34.0	33.4	30.5	25.3	20.9
2012	17.0	18.0	25.6	29.8	36.3	39.7	38.9	34.5	32.4	30.1	25.1	18.9
2013	17.8	18.8	25.7	30.5	37.4	37.7	35.3	31.4	31.4	30.5	24.1	19.9
2014	19.0	19.3	22.0	29.6	33.5	40.0	36.2	35.9	31.4	29.0	25.0	19.1
2015	18.7	20.9	23.0	29.1	35.6	35.3	34.0	34.2	34.2	29.9	23.0	19.5

Note: This is real time data and not meant for litigation.

Table 2 - Meteorological data of mean maximum temperature

	METEORLOGICAL DATA OF MEAN MININMUM TEMPERATTURE (°C),RAWALPINDI											
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2006	3.8	9.7	11.4	15.3	23.0	23.0	24.0	23.3	20.5	15.9	9.4	4.1
2007	1.0	6.6	9.0	15.9	19.8	23.0	21.5	21.8	19.5	12.6	8.2	5.1
2008	3.0	4.9	11.5	15.8	20.7	22.2	22.8	23.0	19.7	15.4	8.1	5.5
2009	3.9	6.4	9.9	14.2	18.7	21.6	24.7	28.3	21.1	14.0	7.5	3.8
2010	3.4	7.9	14.3	17.8	22.0	23.6	24.5	27.2	22.3	17.5	9.9	3.1
2011	2.8	6.8	11.9	15.5	23.0	25.8	24.4	24.3	22.7	16.1	11.2	0.5
2012	2.0	4.5	9.8	16.1	19.6	21.5	26.2	24.0	20.6	15.3	8.4	5.1
2013	2.4	6.9	11.7	16.1	20.8	24.9	24.0	23.2	21.0	17.7	7.1	3.9
2014	2.2	5.5	9.0	14.4	19.2	23.2	23.9	25.1	19.0	15.3	6.5	4.3
2015	4.4	8.4	11.3	17.2	21.1	23.9	24.0	24.6	21.8	12.1	10.3	5.4

Note: This is real time data and not meant for litigation.

Table 3 - Meteorological data of mean minimum temperature

3. Water Resources in the Islamabad-Rawalpindi area

Three water resources are used in the Islamabad-Rawalpindi area: dams, headworks and groundwater. They are detailed in the following subchapters.

3.1. Surface water resources

Due to the location of Islamabad at the foot of the Margalla Hills on the north and the Murree and Kotli Sattian Hills on the east, the area benefits from the natural slope in terms of surface water resources. In fact, various streams flow in and around the city of Islamabad. The main rivers are the Soan and the Kurang River which are draining the area up to the Murree Hills. Both are dammed at Rawal and Simly, respectively. The stream Lai Nullah is draining southward into the Soan River from the mountain front of the Margalla Hills.

Headwork water is diverted from springs located at Saidpur, Nurpur and Shahdara. Furthermore, Kurang River seems to be discharged at another location than the Rawal dam.

The different surface water resources are subject of the following subchapter. The map on figure 3 shows the location of these resources.

3.1.1. *Soan River*

Soan River rises near the small village Bun in the foothills of Patriata and Murree and drains much of the water of the Potohar region. Its water is stored in the Simly Dam which is illustrated afterwards. After treading a long path of 250 km, this relatively small stream falls into the Indus River near by the Kalabagh Dam close to Pirpiyahi.

3.1.2. *Kurang River*

Kurang River is the main stream draining the area of Islamabad. Its mainly tributary is Gumrah Kas which drains westward into the Kurang River from the area between Kurang and Soan River.

3.1.3. *Lai Nullah*

Lai Nullah stream flows from the Margalla Hills down through the city of Rawalpindi discharging into Soan River. The stream carries most of the liquid waste from Rawalpindi and contributes greatly to the pollution of the Soan River below their confluence.

3.1.4. *Rawal Lake or Rawal Dam*

Rawal Lake is an artificial reservoir located in an isolated section of the Margalla Hills National Park. It's fed by water from Kurang River and other small streams coming from the Margalla Hills like the Jinnah Stream. Its storage capacity is about 58,600,000 m^3, the discharge capacity of its spillway is about 2,300 m^3/s. It provides drinking water for the population of Islamabad and Rawalpindi. Mean annual water available is 72 MGD (million gallons per day).

3.1.5. *Simly Dam*

Simly dam is located on the Soan River at some 30 km east of Islamabad and fed by melting snow and natural springs of Murree Hills. It's the largest reservoir of drinking water for the population of Islamabad. The storage capacity of the dam is about 35,463,000 m^3 with a spillway of discharge capacity of 1,275 m^3/s. Mean annual water available is 68 MGD.

3.1.6. *Khanpur Dam*

Khanpur Dam is located on the Haro River in the north of the Margalla Hills at about 40 km of Islamabad. Its stored water provides domestic water to Rawalpindi and Islamabad as well as irrigation water for agriculture and industries in the surroundings of these cities. The storage capacity of the dam is about 140,000,000 m^3. Mean annual water available is 198 MGD.

3.1.7. *Headworks*

The capacity of the four headworks sources mentioned is as follows:

- Kurang River: 4 MGD,
- Saidpur: 0,8 MGD,
- Nurpur: 0,7 MGD,
- Shahdara: 1,6 MGD.

The exact positions of these discharges are not known due to a lack of information.

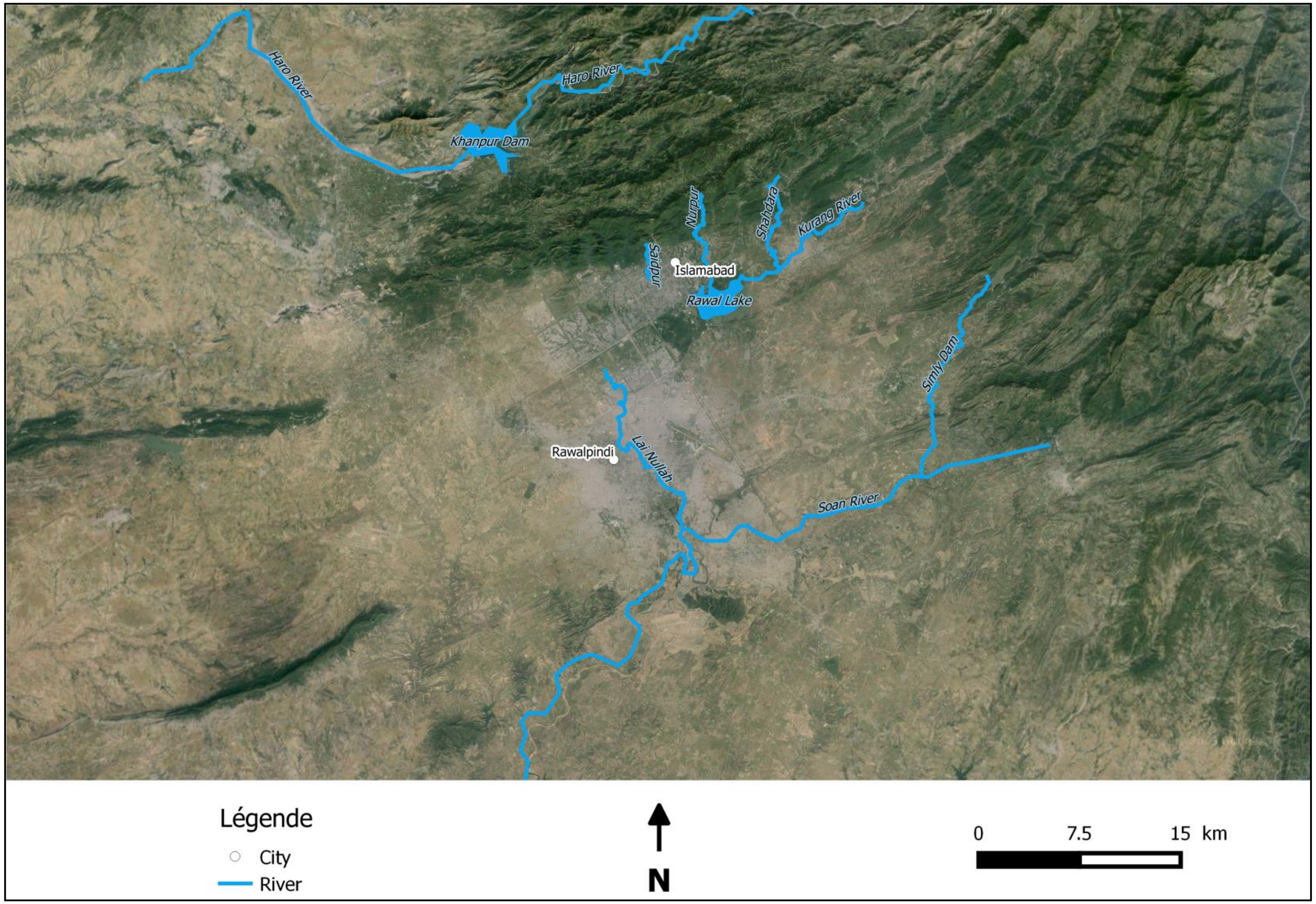

Figure 3 - Location of the different surface water resources in the Islamabad-Rawalpindi area

3.2. Groundwater

Groundwater resources in the Islamabad-Rawalpindi area are mainly contained in and discharged from the recent Quaternary alluvium deposits. Several aquifers, lying upon another, are located in the sector: a superficial aquifer and a deeper aquifer. The presence of these aquifers is conducted by the intercalation of large clayey lenses causing dissection and therefore an insignificant connectivity in some sectors. Recharge is principally due to precipitation and supplied by nearby streams.

The amount of the available groundwater isn't exactly known. Former reports supposed an availability of 86 MGD (HESC, 2014).

The extraction of groundwater is realized by a public bore well network which is supposed to be made up of about 200 bore wells. The amount of private wells is difficult to estimate, but NESPAK study identified 129 tube wells in Islamabad. It is supposed that private water wells are common but current information is requested.

3.3. Water resources use and water demand

The last population census of Islamabad has been held in 1998. The next population census is scheduled for March 2016 (Pakistan Bureau of Statistics). In 1998, population has been 805,235. The Capital Development Authority (CDA) published in 2013, that present population of 1.757 million is likely to increase to 4.443 million in the year 2050. According to the CDA, the growth rate is about 5.7 % per year.

Average water demand is given by the CDA and is currently expected to be 176 MGD.

The global water groundwater resource use isn't available; however, Nespak study collected information about 129 groundwater tube wells in Islamabad. Their total daily discharge is about 63 MGD. HESC study pointed out a groundwater resource use of 34 MGD provided by some 180 public tube wells (2007).

This chapter needs current information to deliver workable outcomes for the present report: current and future water demand is necessary as well as information about the water resource use (domestic, agricultural, industrial) and the part of groundwater employed by these different sectors.

4. Geology and Hydrogeology in the study area

4.1. Geological context

The geological structure and stratigraphy of the Islamabad-Rawalpindi area is very complex due to the convergence of the Pakistan-India and Eurasian tectonic plates and their collision that began about 20 million years ago.

The geological history records a long period of gentle geological fluctuations and slow deposition in the study area while the Pakistan-India plate drifted northward. This period is followed by more vigorous tectonic processes and rapid deposition since the convergence of the Pakistan-India and Eurasian plates. Therefore, the period from the Middle Jurassic to the Lower Miocene (150 million years) is represented by only 675 m of primarily marine sedimentary rocks, whereas the last 20 million years are represented by more than 7 570 m of continental sedimentary rock.

The last 1,5 million years are characterized by a domination of erosion over deposition, hence, the preserved sediments are thin and discontinuous alluvium and eolian silt.

The sedimentary rocks exposed in the Islamabad area date from the Middle Jurassic to the Quaternary. Three structural zones can be pointed out in the study area:

- **Mountainous Margalla Hills in the north**: Jurassic through Eocene limestone and shale complexly folded and thrust along the Hazara fault zone;
- **South of the Margalla Hills**: the southward-sloping piedmont bench (piedmont fold belt) is underlain mainly by truncated folds in the sandstone and shale of the Rawalpindi Group;
- **Southernmost area**: fluvial sandstone, claystone and conglomerate deposits along the axis of the Soan syncline west-southwestward.

The Hazara fault zone is located in the north of the Islamabad-Rawalpindi area and affects a scope of about 25 km of width and 150 km of length. The area is convex to the south and extends west-southwestward away from the Himalayan syntaxis. Hence, the thrust and fold structure of the Margalla Hills immediately north of Islamabad is complex: there are at least five principal thrust sheets repeating the pre-Miocene marine section.

In the piedmont fold belt area, Pleistocene conglomerate, overlying sandstone of the lower Miocene, is folded in the broad anticline at Shakar Parian Park in Islamabad.

The Soan syncline is an asymmetric, faulted fold of regional extent, plunging west-southwestward where fluvial sandstone, claystone and conglomerate were deposited. The maximum width of the synclinal in the study area is about 11 km, but the fold extends 100 km to the southwest.

Four different main lithological units are present in the Islamabad-Rawalpindi area:

- Sandstone and limestone of Cretaceous age,
- Margalla Hill limestone of Eocene age,
- Nimadrics of Miocene to Lower Pleistocene,
- Deposits of Pleistocene and Quaternary age.

The stratigraphic section of consolidated rocks in the Islamabad-Rawalpindi area is shown in figure 4 below.

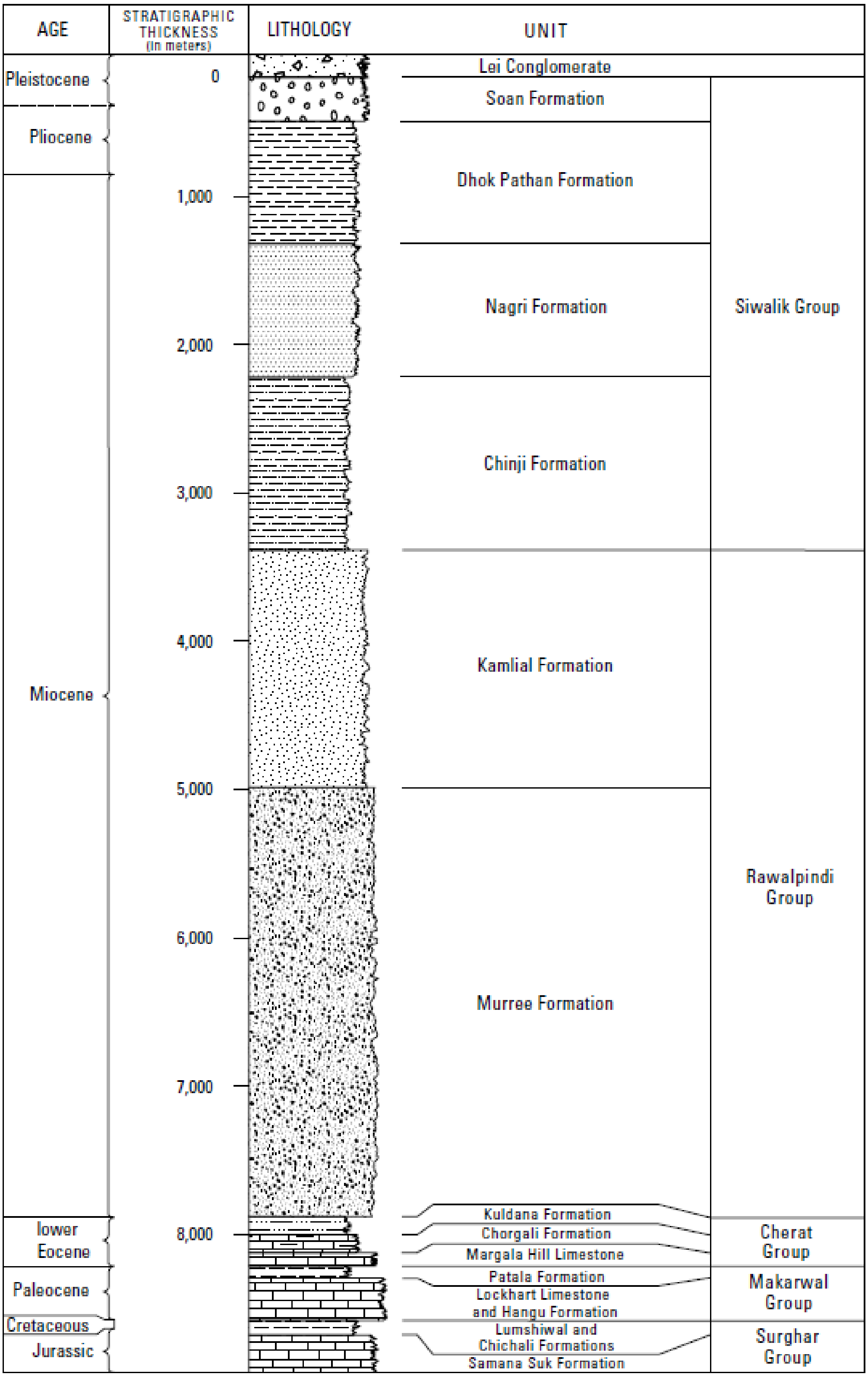

Figure 4 - Generalized composite stratigraphic section of consolidated rocks in the Islamabad-Rawalpindi study area (source: Environmental Geology of the Islamabad-Rawalpindi Area, Northern Pakistan, Sheikh and al. [reference 3])

The section of interest for the present study is mainly concerning Pleistocene and Holocene formations. The table 4 below is showing the different formations and their main lithology characteristics.

Unit name	Lithology	Thickness (m)	Map Symbol*
Stream-channel alluvium	Unconsolidated, channel-crossbedded, moderately sorted channel and bar deposits of sand and gravel	3	S
Flood plain and fan alluvium	Flood plain: Unconsolidated, channel-crossbedded, moderately sorted channel and bar deposits of sand and gravel, overlain by relatively thin veneer of silt, clay and organic material Fan alluvium: Primarily unconsolidated sand and gravel of a mixture of the lithologies found in the tributary watersheds. The surface may be covered with thin soil of silt and clay. Poorly sorted and beddes. Debris-flow deposits are common	Flood-plain alluvium: 6 Fan alluvium: 20	F,A
Alluvium and windblown silt	Eolian silt and stream-channel, flood plain, terrace and slope-wash alluvium	10	
Terrace alluvium	Unconsolidated, channel-crossbedded, moderately sorted channel and bar deposits of sand and gravel, overlain by relatively thin veneer of silt, clay and organic material	6	T
Potwar Clay	Windblown clay and silt and subordinate amounts of alluvial gravel. Fine grained, hard, compact and calcareous	1-35	P,B
Lei Conglomerate	Subangular cobbles of Eocene limestone as large as 30 cm. Matrix of reworked eolian silt. Conglomerate is thickly interbedded with sandy silt beds and gravel beds.	Exposed thickness is 106 m. But one drill hole penetrated about 152 m.	C

***The map symbol refers to the local geological map on figure 5**

Table 4 - Lithology characteristics of geological units of the Pleistocene and Holocene ere (source: Environmental Geology of the Islamabad-Rawalpindi area, Northern Pakistan, Sheikh and al. [reference 3])

The quaternary deposits are generally heterogeneous. The subsurface mainly presents silt and clay deposits. The gravel beds are present in discontinuous layers with silty clay. Their thickness decreases in the south and west. The average thickness of the alluvium is more than 200 m, and can even be 300 m in some areas.

The following map is pointing out the local geology in the Islamabad-Rawalpindi area. Two cross sections are showing the geological characteristics in the deeper horizons.

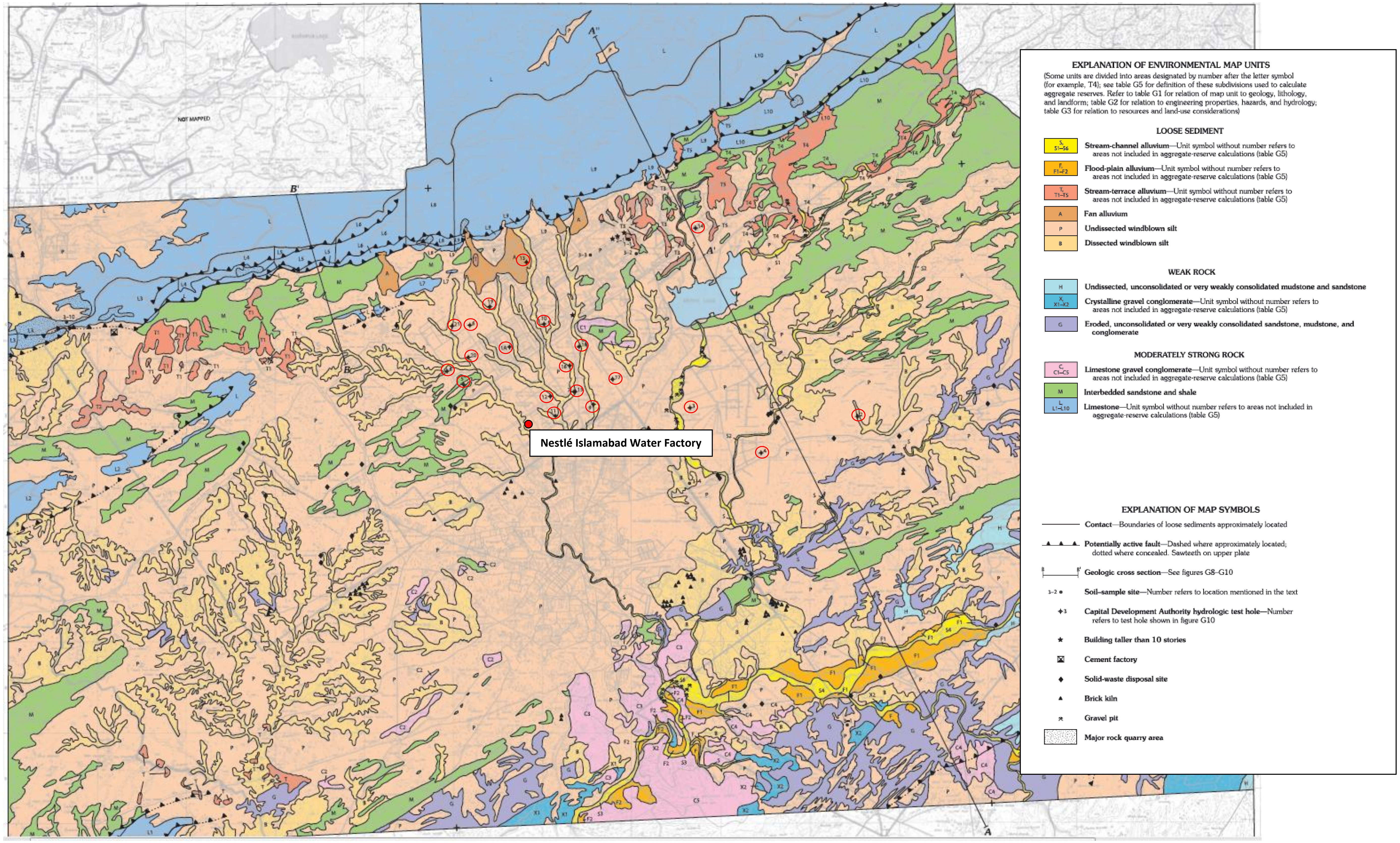

Figure 5 - Local geological map of the Islamabad-Rawalpindi area (source: Environmental Geology of the Islamabad-Rawalpindi area, Northern Pakistan, Sheikh and al. [reference 3])

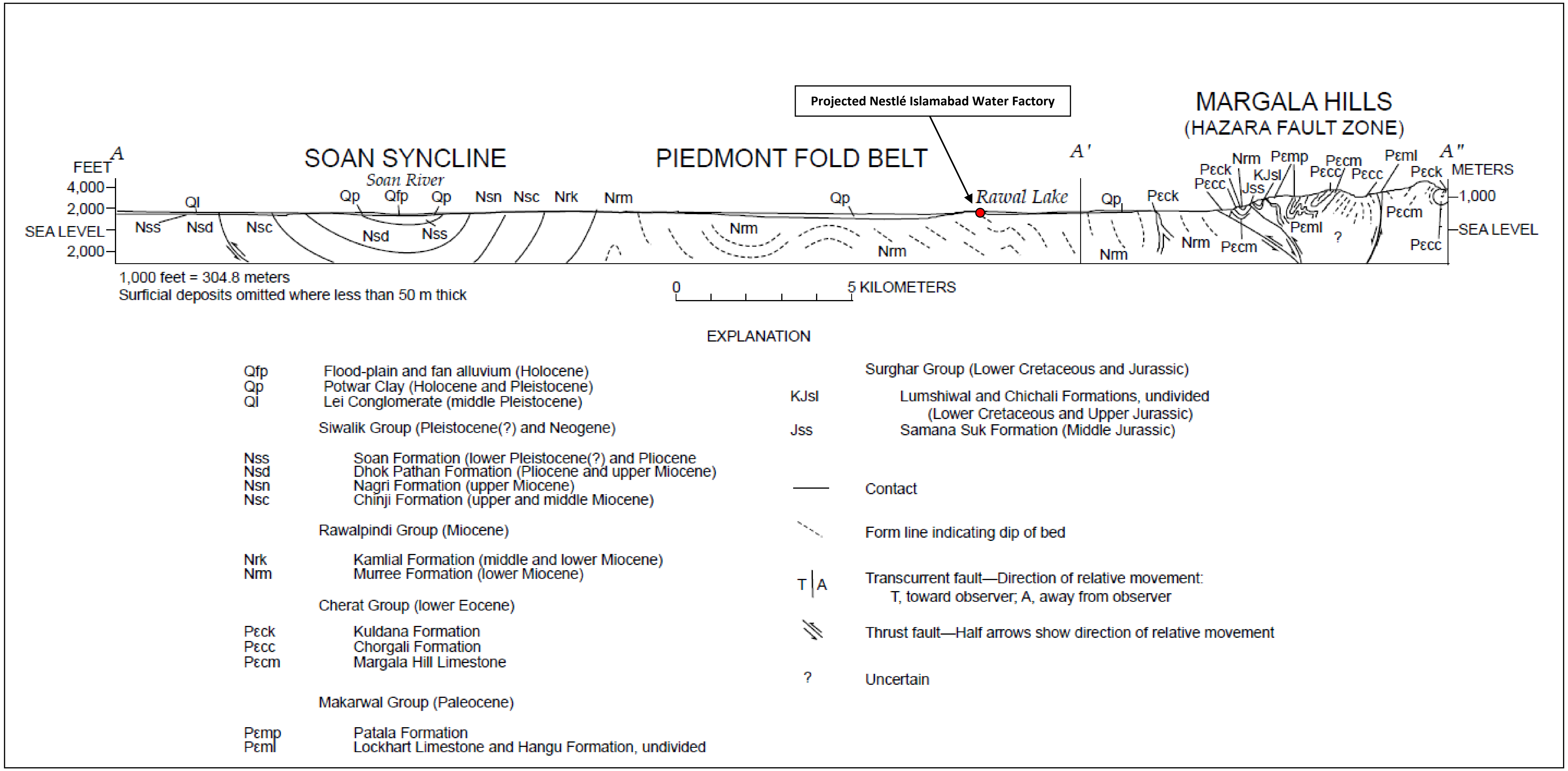

Figure 6 - Geological cross-section A –A'-A'' (source: Environmental Geology of the Islamabad-Rawalpindi area, Northern Pakistan, Sheikh and al. [reference 3])

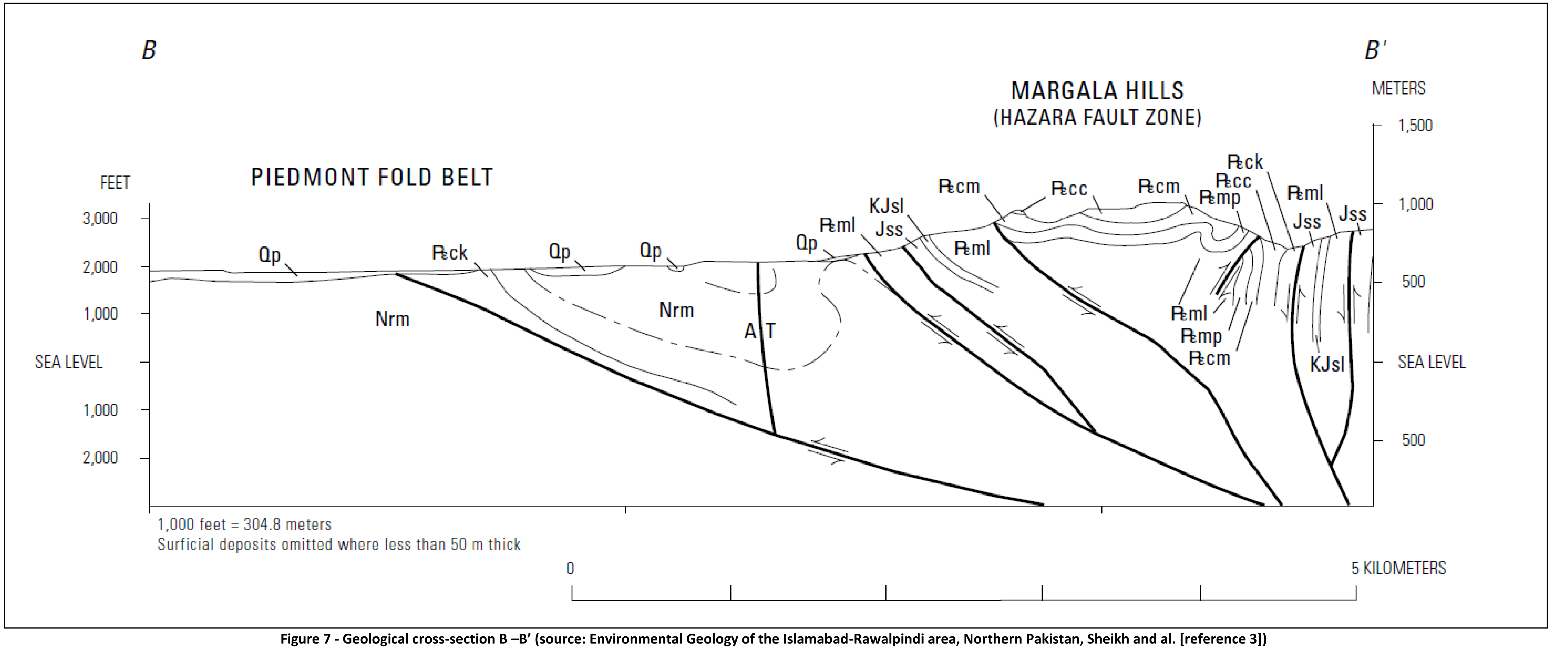

Figure 7 - Geological cross-section B –B' (source: Environmental Geology of the Islamabad-Rawalpindi area, Northern Pakistan, Sheikh and al. [reference 3])

4.1.1. *Local geological context*

The Nestlé Water Factory is located in Sector I-10/3 of Islamabad. An exploratory borehole in the area (AVA Building) presents the following lithological cross section:

- 0 to 13.7 m: Potwar Clay
- 13.7 to 15 m: Boulder
- 15 to 30 m: Clay
- 30 to 39 m: Fine gravel
- 39 to 41 m: Boulder
- 41 to 50 m: Mixture of clay and boulder
- 50 to 62 m: Clay
- 62 to 68 m: Boulder
- 68 to 75 m: Mixture of clay and boulder
- 75 to 92 m: Boulder
- 92 to 94 m: Mixture of clay and boulder
- 94 to 103.6 m: Dominant Clay
- 103.6 to 113 m: Sandstone/sand and shale
- 113 to 129 m: Dominant shale

This lithological cross-section highlighted out the alternation of permeable (boulder, gravel) and less permeable formations (clay, mixture of clay and boulder) in the study area. The thickness of boulder beds varies from 1.3 to 17 meters, the formation composed of a mixture of boulder and clay is about 2 to 9 m thick.

4.2. Hydrogeological context

The analysis of the hydrogeological context of the Islamabad-Rawalpindi area has highlighted the presence of a shallow aquifer and a deeper aquifer. The shallow aquifer is composed by the Holocene and upper Pleistocene alluvium units. The deeper aquifer is contained in the Lei Conglomerate formation of Pleistocene.

The table 5 below is pointing out the groundwater characteristics of each geological unit concerning the present study.

Unit name	Aquifer	Groundwater availability
Stream-channel alluvium	Superficial	Good groundwater at shallow depth, high permeability, poor drainage. Any disturbance affects quality of groundwater
Flood plain and fan alluvium	Superficial	Good groundwater at shallow depth, high permeability, poor drainage
Alluvium and windblown silt	Superficial	Little groundwater resources expected, may contain groundwater in the alluvium beds
Terrace alluvium	Superficial	Shallow groundwater available. High permeability.
Potwar Clay	Superficial	Yields little groundwater but may contain gravel aquifers
Lei Conglomerate	Deep	High infiltration rate and transmissivity make the unit a good groundwater recharge medium and aquifer

Table 5 - Groundwater availability of geological units of the Pleistocene and Holocene age (source: Environmental Geology of the Islamabad-Rawalpindi area, Northern Pakistan, Sheikh and al. [reference 3])

Sheikh and al. [3] consider the uncemented conglomerate beds of the Lei Conglomerate as the most important groundwater aquifer in the area. However, the alluvium formations overlying the Lei Conglomerate present a shallow water table and are therefore often exploited by municipal and private wells.

It is to mention that the presence of these aquifers is conducted by the intercalation of large clayey lenses causing dissection and therefore an insignificant connectivity in some sectors which aren't precisely located (cf. Figure 9). HESC report even suggests that there are five aquifer levels in the area. Due to the lithological heterogeneity of the study area, the presence of this aquifer structure doesn't necessarily exist in all parts of the area.

The bedrock in the area consists of folded and faulted sandstone and claystone of the Rawalpindi Group, some soft sandstone and claystone from the Kuldana Group, harder limestone from the Chorgali Formation toward the north and some Siwalik Group sandstone and claystone toward the south. Depth to bedrock exceeding 100 m are common over much of the area, even close to outcrops.

The flow direction is supposed to follow a southward/southwestward axis. There isn't a local piezometric map available. Consequently, no hydraulic gradient could be calculated. In view of all information missing, no piezometric map has been drawn in the two studies. It would be necessary to dispose of a piezometric monitoring network precisley located, and water table measurement campaign, to design a realistic piezometric map. The PCRWR (Pakistan Council of Research in Water Resources) Headquaters Islamabad is monitoring the water table twice a month since 1986 through a monitoring network of piezometers. Unfortunately the location of each monitoring well as well as their technical caracteristics are unknown. The evolution of the water table is alarming: in 1986, the water table was about 12 m below the ground surface, in 2003, the average water level depth is about 30.5 m below surface (cf. Figure 8). The average rate of decline was 1.09 m per year during these 17 years of monitoring between 1986 to 2003. Between 2003 and 2015 the decline still continues: the average water level in 2015 is about 35.7 m. The average rate of decrease was 1.4 m per day during the 12 years of monitoring.

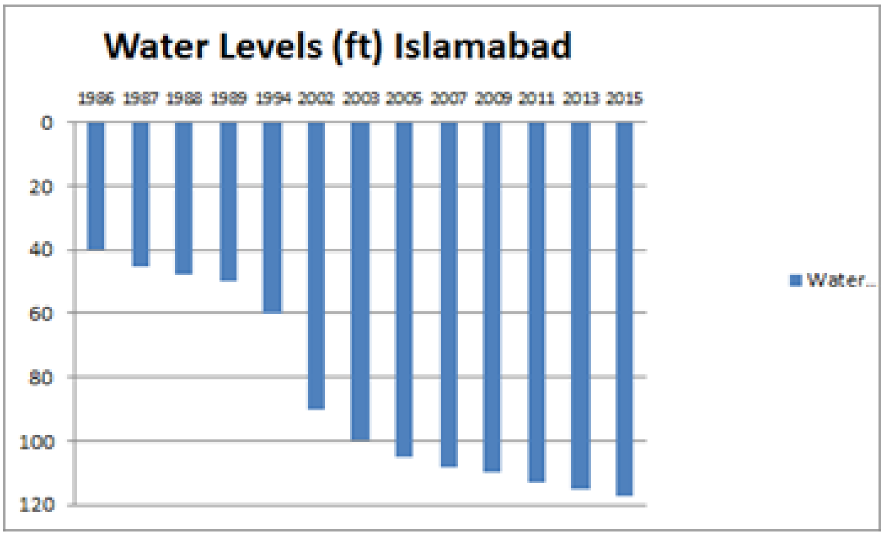

Figure 8 - Groundwater level evolution in Islamabad since 1986

The altitude of the water level decreases from about 600 m asl at the foot of the Margalla Hills to less than 450 m asl near the Soan River, so that the saturated zone generally is between 2 and 20 m below the ground surface (Sheikh and al.).

The Capital Development Authority (CDA) drilled 21 hydrogeologic test holes in 1980 in Islamabad and the surroundings. The location of the test holes is shown in figure 5. The lithology of each test hole is illustrated below in figure 9. The average water table of these test holes is about 8 m below ground surface in 1980.

The sources of recharge are precipitation and probably a supply by the nearby rivers. However, the local geological map (cf. figure 5) highlighted out that a major part of the area is covered by windblown silt (Potwar clay). This formation is characterized by a rapid runoff and drained the area southwestward. Hence, recharge to the aquifer through these deposits is likely difficult. Recharge is possible at sectors where alluvium formations are exposed. These zones are especially located at the foot of the Margalla Hills.

It seems that pollution mainly percolates nearby the river network (Sheikh and al.), indicating discharge of surface water to groundwater. Therefore, it is supposed that the Kurang River as well as the Lei Nullah recharge the groundwater, especially during rainy season. No data is available to prove these presumptions.

Another source of recharge could be the Miocene bedrock below the Quaternary formations and particularly the interbedded sandstone and shale of the Rawalpindi Group. The sandstone may be favorable as aquifers and artesian conditions may exist, explaining an ascending inter-formational flow.

Extended outcrops of the Rawalpindi Group are principally located in the east part of the map in figure 5, but little outcrops could also be exposed at the northwest contributing to the recharge of the aquifer.

The groundwater facies as well as the quality is missing in former reports and would be interesting to characterize, especially to identify the provenance of the groundwater at different zones within the Islamabad-Rawalpindi area.

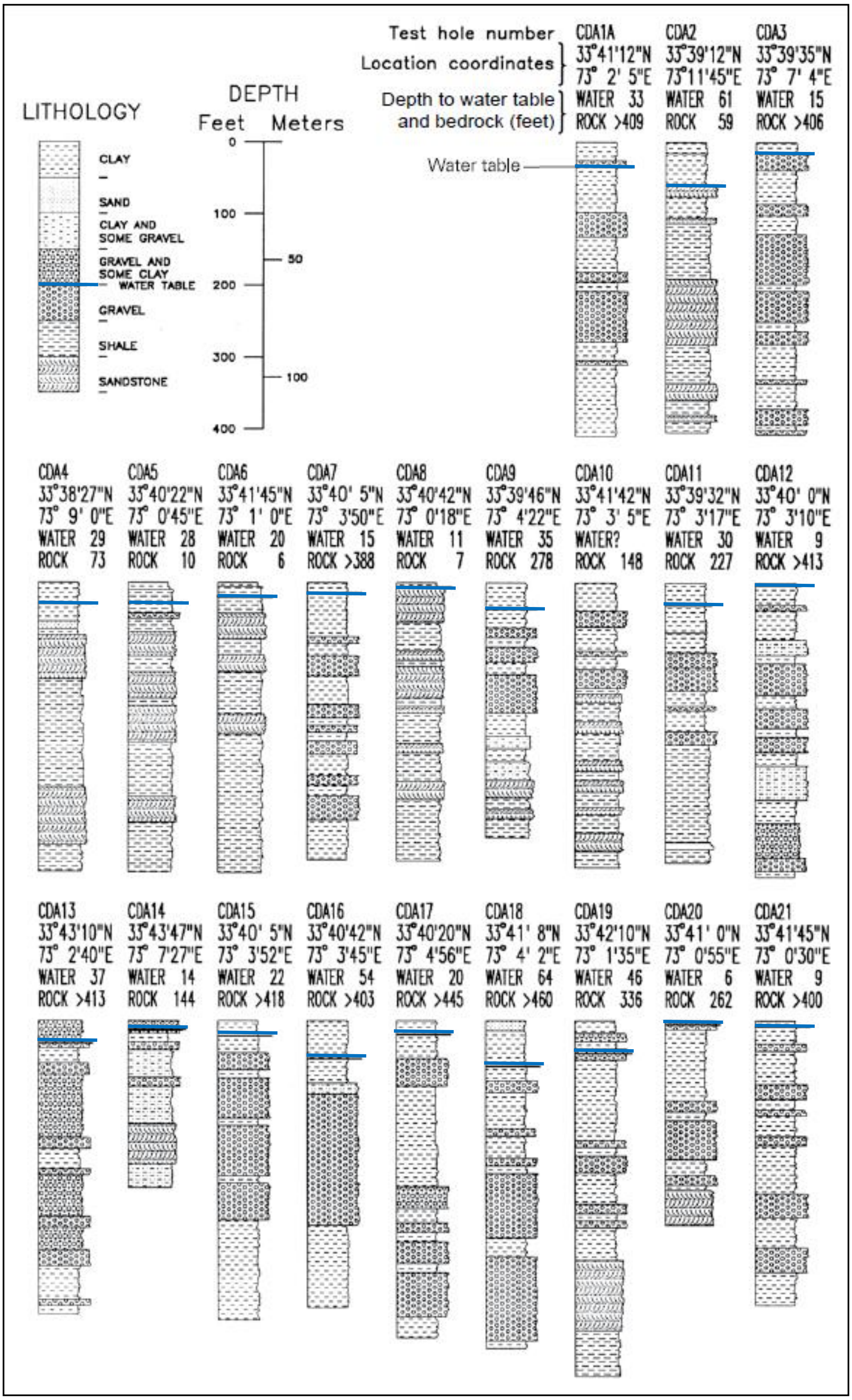

Figure 9 - Lithology logs of the CDA around Islamabad (source: Environmental Geology of the Islamabad-Rawalpindi area, Northern Pakistan, Sheikh and al. [reference 3])

4.2.1. *Groundwater quality*

A water quality monitoring report of 2005/2006 is available, synthesizing data of 20 tube wells located in Islamabad. The water is mineralized, the average conductivity is 728 µS/cm with values varying between 618 and 823 µS/cm. The pH is neutral (7.05) and turbidity is low (0,4 NTU).

The following figures show the characteristics of the water samples. All samples present a chemical facies that contains bicarbonates with calcium and magnesium (see Piper diagram). Schoeller and Berkaloff diagram in figures 10, 11 and 12 highlighted out that all water samples are quite similar.

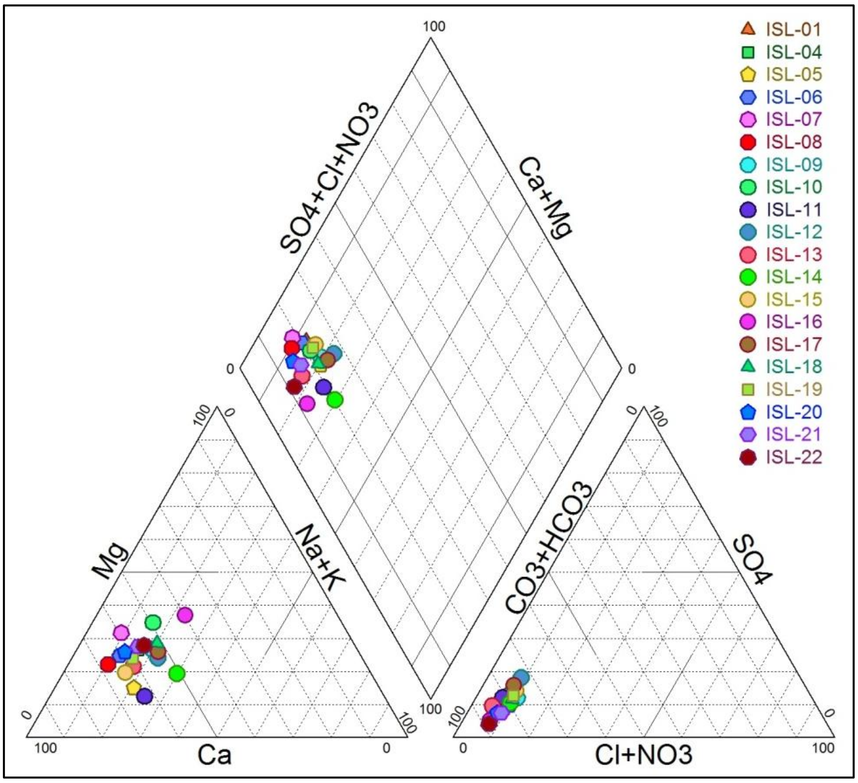

Figure 10 - Piper diagram of analyzed water samples in Islamabad (2005/2006)

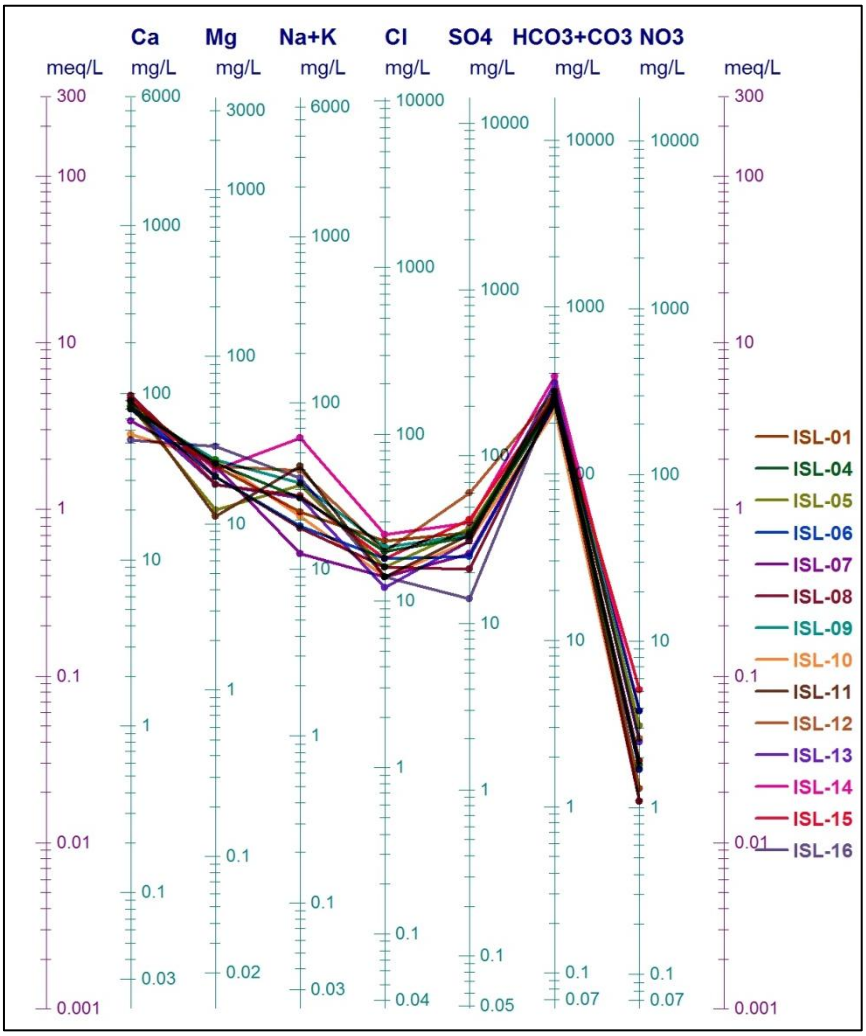

Figure 11 - Schoeller and Berkaloff diagram of anaylzed water samples ISL-01 and ISL-04 to ISL-16 in Islamabad (2005/2006)

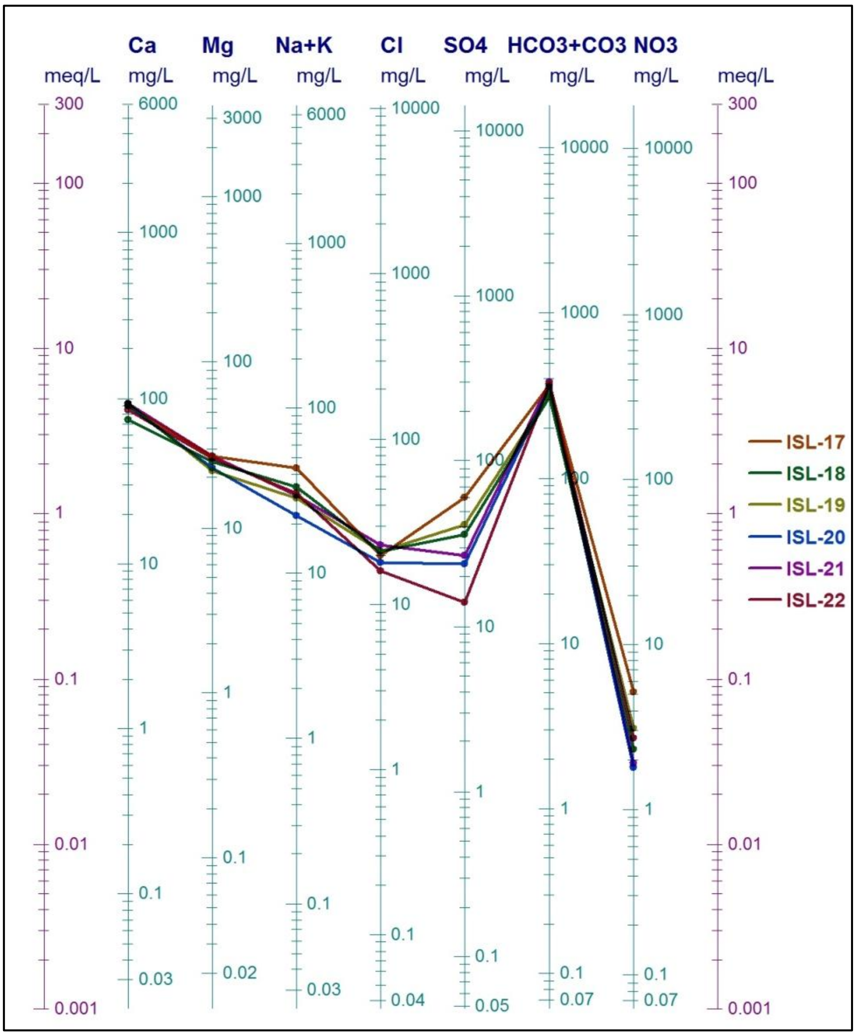

Figure 12 - Schoeller and Berkaloff diagram of anaylzed water samples ISL-17 to ISL-22 in Islamabad (2005/2006)

Concentrations of arsenic and lead are below the French drinking water guideline and the World Health Organization (WHO) drinking water guideline. There are no other metals that have been analyzed in 2005/2006.

Concerning the bacteriological quality of the groundwater, almost all samples exceed the drinking water guideline for the parameter of the total coliforms (only on six wells, zero coliforms have been detected).

4.2.2. *Local hydrogeological context*

The exploratory water well located in Sector I-10/3 of Islamabad (AVA Building) was used to carry out a step drawdown test and a long duration pumping test in 2002.

The saturated thickness of aquifer contributing towards well screen is 96.8 m. The target aquifer is the Lei Conglomerate of the deeper horizons.

The long duration constant rate pumping test was conducted for 99 hours at a discharge rate of 21 m^3/h (5548 GPD). The data analysis identifies an aquifer loss of about 1.86 m.

The transmissivity of the aquifer has been adopted to be 4.8×10^{-3} m^2/s. Storage coefficient is about 1×10^{-4} and hydraulic conductivity is estimated to be 4.9×10^{-5} m/s.

The water level trend of the deep well n°2 of the Nestlé Water Factory (DW-2) is monitored since 2013 (cf. Figure 13). A single measure has been done in 2002. Between 2002 and 2013, the water level presents a decline of 6.2 m. However, in the years between july 2013 and october 2015, water level rose up about 3 m (linear trend line).

drip irrigation?

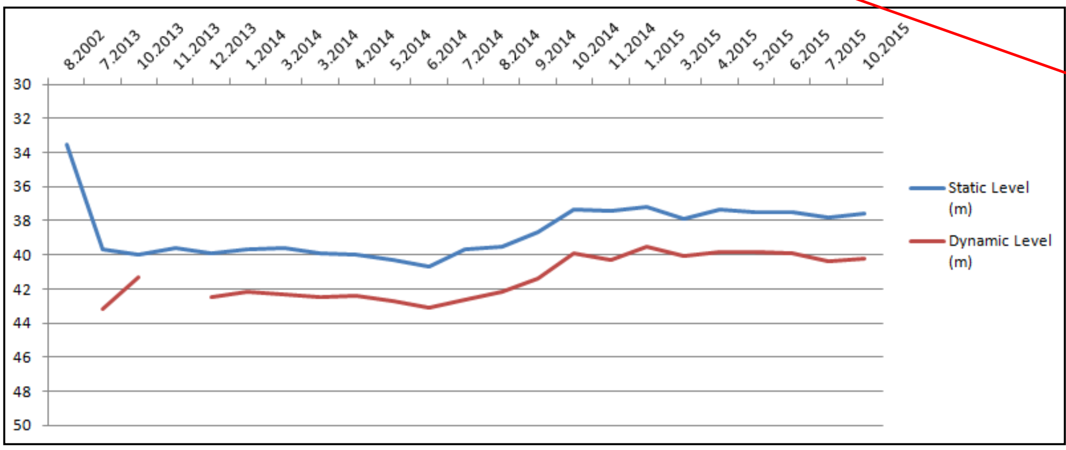

Figure 13 - Water level trend of the Nestlé Deep Well n°2 (DW-2)

The description of the hydrogeological context of the study area has pointed out that available information are much to superficial aquifer and not exhaustive enough to characterize precisely the groundwater system.

It would be requested to collect further information to detail the hydrogeological context and estimate more realistically the groundwater sustainability (cf. chapter 5).

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5. Assessment of the sustainability of the water resource

5.1. Definitions

The assessment of the **sustainability** of the water resource requires a joint approach:

- **qualitative assessment** : the cross analysis of the following criteria allows the evaluation of the level of pollution risk:
    - evaluation of the intrinsic vulnerability of the aquifer,
    - identification of possible pollution sources, diffuse and punctual, actual and future.
- **quantitative assessment :** the assessment of the sustainability of the resource is based on a detailed watershed water balance. Actual consumption and future needing (scenario) are to be also integrated.

5.2. Qualitative assessment

The **vulnerability** of an aquifer defines its sensitivity with regards to the transfer of anthropic (or natural) pollutions. It translates the possibility that a pollutant can, under natural runoff conditions, percolate from the surface to the water table, and then eventually reach an identified target (boreholes).

The assessment of the pollution risks for process water supply requires considering the recharge area. Considering the geomorphology of the sector, it seems that the surface formation is not very appropriate for recharge. Actually, the major part of the area is covered by windblown silt which characteristic is a rapid runoff of precipitation.

Nevertheless, Sheikh and al. indicate that large quantities of liquid and solid waste are a major problem and cause extensive pollution of groundwater and surface water. It is established that Lei Nullah is polluted when leaving Rawalpindi city. The stream enters the Soan River as a putrid stream covered with brown foam and probably toxic waste as it passes through industrial areas. It seems that tube wells located near Lei Nullah are producing contaminated water as well.

The quality analysis of 2005/2006 showed absence of arsenic and lead. No other heavy metals neither pesticides have been analyzed. The bacteriological analysis pointed out a presence of total coliforms exceeding the French drinking water guideline and the World Health Organization (WHO) drinking water guideline.

The infiltration area seems thus not to be free of potential pollution sources. Further information, especially concerning the hydraulic connectivity between surface stream water and groundwater, is necessary to deliver workable outcomes for IWRM study.

5.3. Quantitative assessment

5.3.1. *Conceptual Model*

A conceptual model of an aquifer system is a simplified, qualitative description of the physical system. A conceptual model normally includes a description of aquifers and any confining units that make up the aquifer system, boundary conditions, flow regimes, sources and sinks of water and general direction of groundwater flow.

Many of the features relevant to the conceptual model regarding the study have been discussed earlier. The Islamabad-Rawalpindi area is composed by aquifer formations contained in recent quaternary deposits. The different aquifer layers are separated by large clayey lenses causing dissection and therefore an insignificant connectivity in some sectors. There is no information about the hydraulic connectivity between the different aquifer layers as well as between the surface river network and the aquifers.

The main component influencing groundwater conditions in the area is the rainfall contribution to groundwater recharge. The river network seems to be source of recharge, too. However, exploitable data is missing.

The variation of horizontal groundwater hydraulic gradient hasn't been identified. The water level fluctuation of these aquifers is not well-known.

5.3.2. *Groundwater Balance*

In order to calculate an estimated Watershed Water Balance, the available regional water related data had been used (rainfall and evapotranspiration of 8 years in the study area, runoff rate, consumption).

A Thornthwaite water-balance-model had been run and an estimation of the total available groundwater had been calculated.

The area considered for the water balance corresponds to the area of influence of the Nestlé Water Factory well. The following parameters have been used to calculate the area of influence:

- a permanent pumping during a month with a discharge rate of 38 m^3/h (12 hours at 25 m^3/h and 12 hours at 50 m^3/h);
- an aquifer transmissivity of 4.8×10^{-3} m^2/s ;
- an aquifer storage coefficient of 1×10^{-4}.

Hence, a circle of 17 km radius where drawdown exists is obtained. This radius is reduced in the north where Margalla Hills crest constitutes the boundary as well as in the south where Soan River corresponds to the boundary of the influence area. The total area of influence has an extent of 720 km^2 (cf. figure 14).

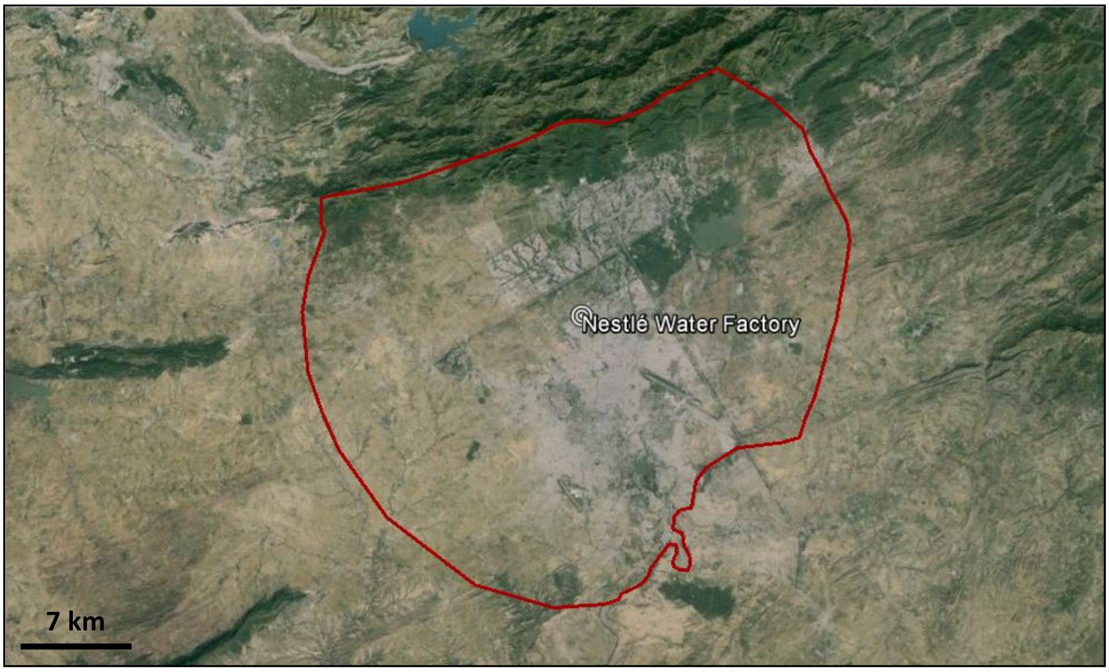

Figure 14 - Zone of influence (720 km²)

Precipitation

Data between 2006 and 2012 reveal an annual mean rainfall in the watershed of 1246 mm. Monthly average precipitation is 103.8 mm. This gives a total annual renewable water volume of 897,120,000 m^3 in the watershed.

Potential Evapotranspiration

Annual average evaporation in the study area is 1283 mm. The monthly mean evaporation is about 106.8 mm. The total potential evapotranspiration is 923,760,000 m^3 in the watershed.

Surface water

The exact mean runoff is unknown. Therefore, hypotheses were made for the runoff rate based on an empirical formula given by the Small Dam Organization in Potohar area of Pakistan. The following value was retained: 147 mm/m^2/yr corresponding to a runoff coefficient of 0.3. The monthly mean runoff is 13.9 mm. The mean runoff on the superficial watershed is 105,840,000 m^3.

Consumption

Consumption is water that leaves the watershed through human action. The main consumptions from the aquifer for water supply have been established from existing data of HESC and NESPAK studies.

The exact groundwater discharge by wells in Islamabad/Rawalpindi isn't known. However some data is given by former studies. NESPAK collected discharge data of 129 wells whose groundwater abstraction mount up to be 63 MGD (87,102,505 m^3/yr). HESC study pointed out a groundwater abstraction about 34 MGD from 180 wells (46,988,640 m^3/yr).

Water balance

Monthly meteorological data from 2006 to 2012 have been used to run a Thornthwaite water-balance model[1]. **The mean recharge value for the aquifer is 261 mm/m²/yr (187,920,000 m^3/yr). The average monthly recharge is about 21.8 mm, but recharge occurs only during six month.** The following figure visualizes the distribution of rainfall, evapotranspiration and recharge during a year.

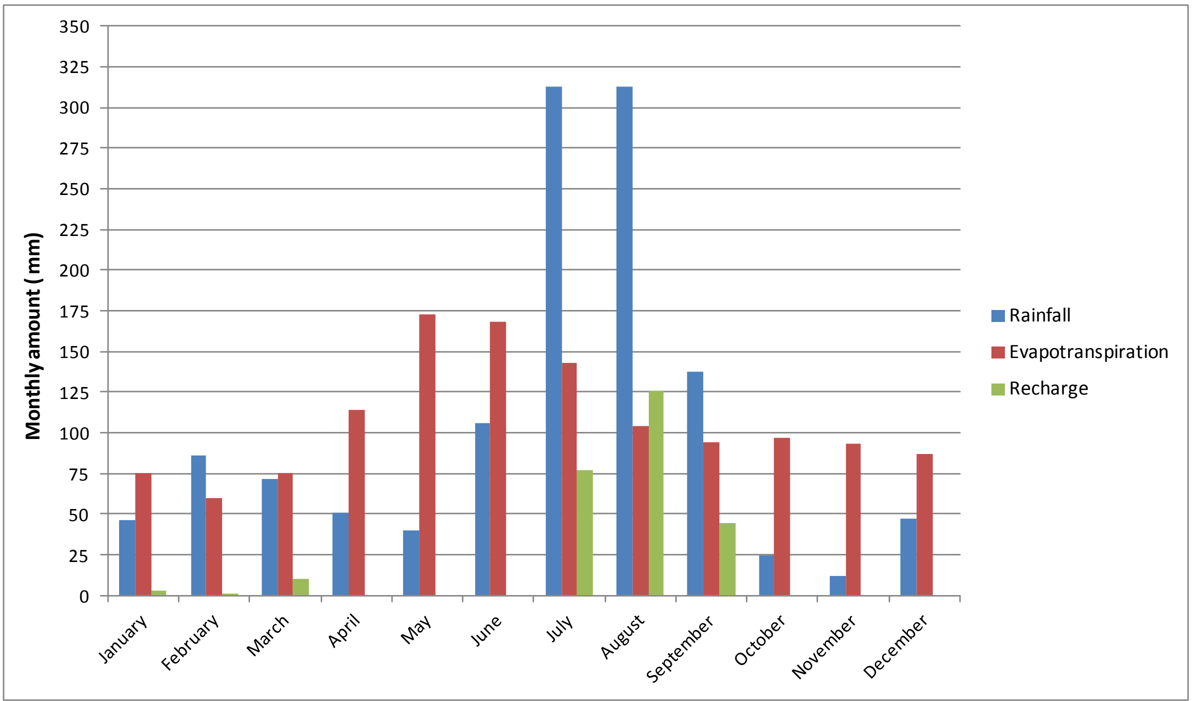

Figure 15 - Annual distribution of rainfall, evapotranspiration and recharge in the Islamabad/Rawalpindi area

The distribution of the recharge during the year isn't uniform. The rainy season occurs in summer (especially in July and August) and the precipitation is much more important than the evapotranspiration. Therefore, recharge happens mainly during the period between July and September. There is also a little recharge period between January and March, but the monthly amount is below 10 mm. This figure explains why there can be an annual recharge even if annual evapotranspiration is higher than annual precipitation.

[1] The water-balance model is based on monthly data of precipitation and evapotranspiration. According to a variable runoff coefficient, the model calculates the monthly runoff and recharge values.

The water budget in the local watershed can be calculated as follows:

$$\Delta S = RR - C$$

Where:

- RR = Rainfall Recharge (mean recharge value obtained by the Thornthwaite water-balance model)
- C = Consumptive uses
- ΔS = Change in storage of water in the watershed

The following tables present the different water balance components for a year as well as for a month.

		Area of influence (720 km²)
Water Budget		**Mm³/year**
Input	Precipitation	897,12
Output	Runoff	105,84
	ETP	923,76
Rainfall Recharge		**187,92**
Consumption		**46,99 to 87,10**
ΔS CHANGE IN STORAGE		***100,82 to 140,93***

Table 6 - Annual Water Balance Components

		Area of influence (720 km²)
Water Budget		**Mm³/month**
Input	Precipitation	74,76
Output	Runoff	8,82
	ETP	76,98
Rainfall Recharge		**15,66**
Consumption		**3,92 to 7,26**
ΔS CHANGE IN STORAGE		***8,4 to 11,74***

Table 7 - Monthly Water Balance Components

The figure 16 below shows a conceptual model of the local aquifer formations.

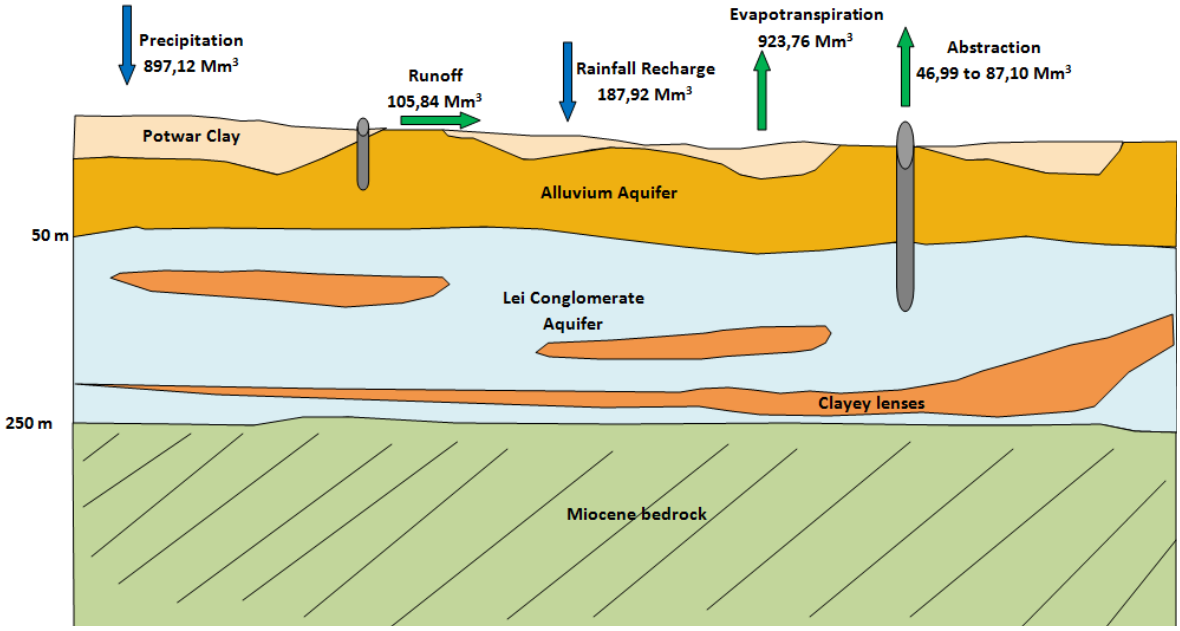

Figure 16 - Groundwater Conceptual Model

Considering an uniform recharge in the area of influence, the annual water balance is positive. Depending on the consumption values retained, the change in storage of water is between 100,82 and 140,93 Mm^3/yr. The monthly change in storage of water varies between 8,4 to 11,74 Mm^3/yr.

Furthermore, the evolution of the Nestlé Deep Well n°2 (cf. figure 13), illustrates that the water level rise up between 2013 and 2015. The linear trend line pointed out an increase of about 3 m.

Besides, it is supposed that surface streams also recharge the aquifer. As no data is available, this component hadn't been included in the water balance. However, recharge to aquifer is probably higher than calculated above.

6. Conclusions and Recommendations

The Islamabad-Rawalpindi area is located within the Potwar Plateau and particularly within the Lei Nullah basin. It's a monsoonal climate zone with rainy hot summers and cool dry winters. The average annual rainfall at the Islamabad weather station between 2006 to 2012 is 1246 mm. The area benefits from the natural south-westward slope in terms of surface water resources providing from the Margalla Hills in the north and the Murree-Kotli-Hills in the northeast.

The area employed three water resources to satisfy their water demand: dams, headworks and groundwater.

When focussing groundwater, the study pointed out that aquifers are contained in Quaternary formation (alluvium, Lei Conglomerate from Pleistocene). The uncemented conglomerate beds of the Lei Conglomerate form the most important groundwater aquifer in the area.

The different layers of the quaternary aquifer are separated by clayey lenses causing dissection and therefore an insignificant connectivity in some sectors which aren't precisely located.

The sources of recharge are mainly the precipitation and the supposed supply by the stream network in the watershed. Contribution could also be provided from the underlying Miocene bedrock, but at this stage, this is only a hypothesis.

According to former information, the public tube well network is made up of about 200 tube wells. Furthermore, private tube wells are common in the area.

The quantitative assessment of the sustainability of the groundwater resource has been realized with the available data. **It concluded that within area of influence of the Nestlé Waters Factory (720 km^2), the water balance is positive**. The monthly data of rainfall and evapotranspiration has identified the period between July and September as main recharge period. Besides, it must be noticed that the recharge is probably higher than calculated because of a contribution of the river network. As there isn't any exploitable data available, this component hadn't been included. Also, it is to notice that the recharge value has been assigned to the complete surface of the area of influence, even if the rainfall contribution to recharge is more important at the foot of the Margalla Hills than elsewhere.

In order to extend and deepen the knowledge of the groundwater system, our recommendations are as follows:

- collect current data of groundwater extraction by wells;
- collect current data of the permanent water table monitoring realized by the PCRWR as well as the exact location of monitored tube wells and their technical caracteristics;

- get information about the water use in the watershed (domestic, agricultural, industrial) and the part of groundwater employed in these sectors;
- collect current tap water needs;
- get general information about the agricultural sector in the watershed and a current land cover map;
- get general information about industrial impact to groundwater.

As a result of the study, it is to mention that the good management of the watershed requires a high knowledge of its structure and its functioning. In order to better characterize the local groundwater system, more consistent data is necessary. There is a real need of regularly water level monitoring, as well as water quality monitoring and groundwater extraction data.

Following the acquisition of the above data, further hydrogeological investigations such as Groundwater Modelling could assess the risk of groundwater depletion and the exact impact of Nestlé Waters abstractions.

A groundwater model is a management tool which allows the representation of an aquifer and of the different environmental components of a site (exploitation wells, piezometry, surface water bodies…).

Depending on the quality and representativeness of input data, groundwater modelling shall permit to:

- assess the impact of withdrawal from a group of wells or individual wells in different flow rate scenarios,
- define a suitable location to implement new production wells and define the potential interferences between the actual and future piezometric implantation plan,
- assess the feasibility of increased groundwater production,
- determinate the optimal exploitation method (running time, flow rates),
- based upon realistic assumptions of contamination, assess the risk of the impact of an accidental or chronic pollution: resulting pollutant concentration in one or a few wells, impact on production, method to be implemented to intercept the pollution upstream the well field.

Comments on using the report

Comment 1
This report, as well as the maps or documents and all other appendices, constitute an indivisible whole; as a consequence, ANTEA GROUP could not be held responsible for part of this report and appendices being communicated or reproduced, as well as any interpretation beyond its own. The same applies for a possible use for other objectives than those defined for the present study.

Comment 2
Reminder is made that survey results are based upon sampling and that this scheme does not allow for the removal of all hazards linked to the heterogeneous nature of the natural or artificial environment surveyed.

Comment 3
This study has been carried out based on exterior information not guaranteed by ANTEA GROUP; it cannot be held responsible with regards to this.

Comment 4
ANTEA GROUP provides its service in compliance with the principles of the AFNOR standard 31-620, dated September 2003. This standard is the basis for the QUALIPOL labelling guidelines, established by UPDS of which ANTEA GROUP is a member. ANTEA GROUP complies with MEEDDAT policy recommendations concerning the management of polluted sites and grounds, initiated in February 2007 and expressed in the circulars of 2007. The work forecasted above meets QUALIPOL codification.

Data Sheet

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